Some Satellite rainfall products:

CMORPH (http://www.cpc.ncep.noaa.gov/products/janowiak/cmorph_description.html)

The main inputs to the Climate Prediction Center (NOAA-CPC) MORPHing technique (CMORPH) are 1) Infra Red data from the US Geostationary Operational Environmental Satellites GOES-8/10, 2), the European Meteosat-5/7and the Japanese Geostationary Meteorological Satellite GMS-5, and 2) PMW derived precipitation data from the TRMM Microwave Imager (TMI), the Special Sensor Microwave/Imager (SSM/I), and the Advanced Microwave Sounding Unit (AMSU)(Thiemig, 2014). In CMORPH the precipitation estimates are based PMW and from infrared (IR) data which serves to interpolate between two PMW-derived rainfall intensity fields. This is done in two steps: (1) Atmospheric motion vectors from two successive IR images are generated at 30-minute intervals and (2) the derived motion field is used to propagate the precipitation estimates derived from the different PMW sources (modified after Joyce, Jonowiak, Arkin, & Xie, 2004).

African Rainfall Estimate (RFE) RFE (http://www.cpc.ncep.noaa.gov/products/fews/rfe.shtml)

The RFE 2.0 rainfall product is provided by the NOAA African Precipitation Estimation Algorithm which is based on IR (Meteosat-7 every 30 minutes) and PMW (SSM/I every 6 hours and AMSU every 12 hours) data as well as on Global Telecommunication System (GTS) rain gauge station data which are taken to be true rainfall within 15-km radii of each station (Thiemig, 2014). Rainfall estimates are generated in two steps as well: first, satellite data sources are linearly combined through a Maximum Likelihood (ML) estimation method to eliminate data gaps and to decrease random errors and systematic bias. Secondly, bias correction is implemented on a grid-to-grid basis using the GTS rain gauge stations to correct for quantitative deviations (Herman, et al., 2010).

Tropical Rainfall Measuring Mission (TRMM) (http://trmm.gsfc.nasa.gov/)

The Tropical Rainfall Measuring Mission provides good estimates of global precipitation from a wide variety of modern satellite born precipitation related sensors. The algorithm of TRMM 3B42RT;; TRMM 3B42 v7, which is currently the most commonly used among the TRMM rainfall products, is executed in four steps: (1) PMW precipitation estimates are calibrated and combined, (2) IR precipitation estimates are generated using the calibrated PMW data, (3) both IR and PMW data are then combined, and (4) rescaled on a monthly basis using rain gauge data. Hence, the main input sources for the TRMM are IR data from geostationary satellites, PMW data from TMI, SSM/I, AMSU and the Advanced Microwave Sounding Radiometer-Earth Observing System (AMSRE)(Thiemig, 2014).

Meteosat Second Generation – Multi-Sensor Precipitain Estimate (MSG-MPE) (http://oiswww.eumetsat.org/IPPS/html/MSG/PRODUCTS/MPE/) (Text adapted from MSc study by Ataklti, 2012)

The Multi-Sensor Precipitation Estimation (MPE) product consists of the near-real time rain rate in mm/hr for each Meteosat image in original pixel resolution 3 km and is most suitable for convective precipitation in areas with poor or no radar coverage like Africa and Asia (Thomas et al., 2002). The EUMETSAT Multi-Sensor Precipitation Estimate (MPE) uses the combination of a direct (SSM/I) and indirect rain rate retrieval (MSG IR brightness channel) that have a higher accuracy and higher spatial and temporal resolutions. Rainfall estimation from satellite developed in MPE gives continuous and accurate rainfall data and this is related to IR brightness temperature for the rain rate retrieval which is suitable for both tropical and subtropical convective precipitation areas and thus the quality of meteorological products are improving using MSG data (Thomas, 2003).

Satellite rainfall Data Processing (text adapted from MSc study by Mpundu Sendama, 2015)

Satellite based rainfall and evapotranspiration products at daily base can be downloaded from the ISOD toolbox via the Integrated Land and Water Information System (ILWIS). Product images can be imported in ILWIS as raster images. For each image of a time series the same georeference file should be used. In the MSc study by Sendama, 2015, CMORPH precipitation product is used for Rwanda. In the data processing, the hourly images at 8km estimates were aggregated to daily rainfall estimates by stacking 24 CMORPH 8km×8km raster maps to make up one day in a maplist in ILWIS GIS software. Rwanda's hydrological and meteorological shapefiles including stations' locations and Nyabarongo basin extent with its sub-basins, were also imported to ILWIS. A LatLon WGS84 georeference for the study area was created to visualize all images and lists. Raster maps were stacked and pixel values were systematically extracted as data time series. Pixel values can be directly compared to station values for pixels that overlay a station (See Figure 1).

Finally the time series data was exported to the excel spreadsheet containing the *in-situ* measurements for further assessment (see Figure 2 where a flow chart is shown).
The same procedure is applies to the satellite meteorological products in Table 1 for comparison purposes.

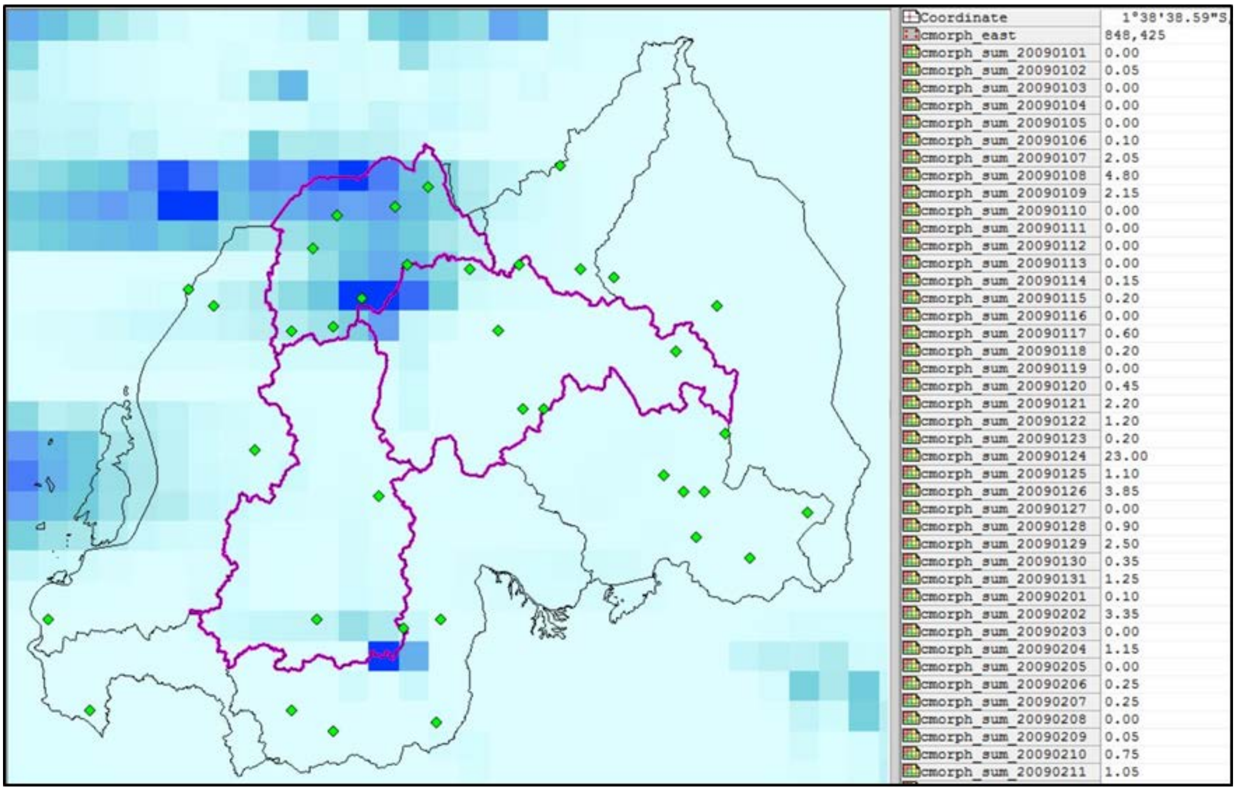

Figure 1: CMORPH 8km maplist for 2009-2013 (Source Sendama, 2015)

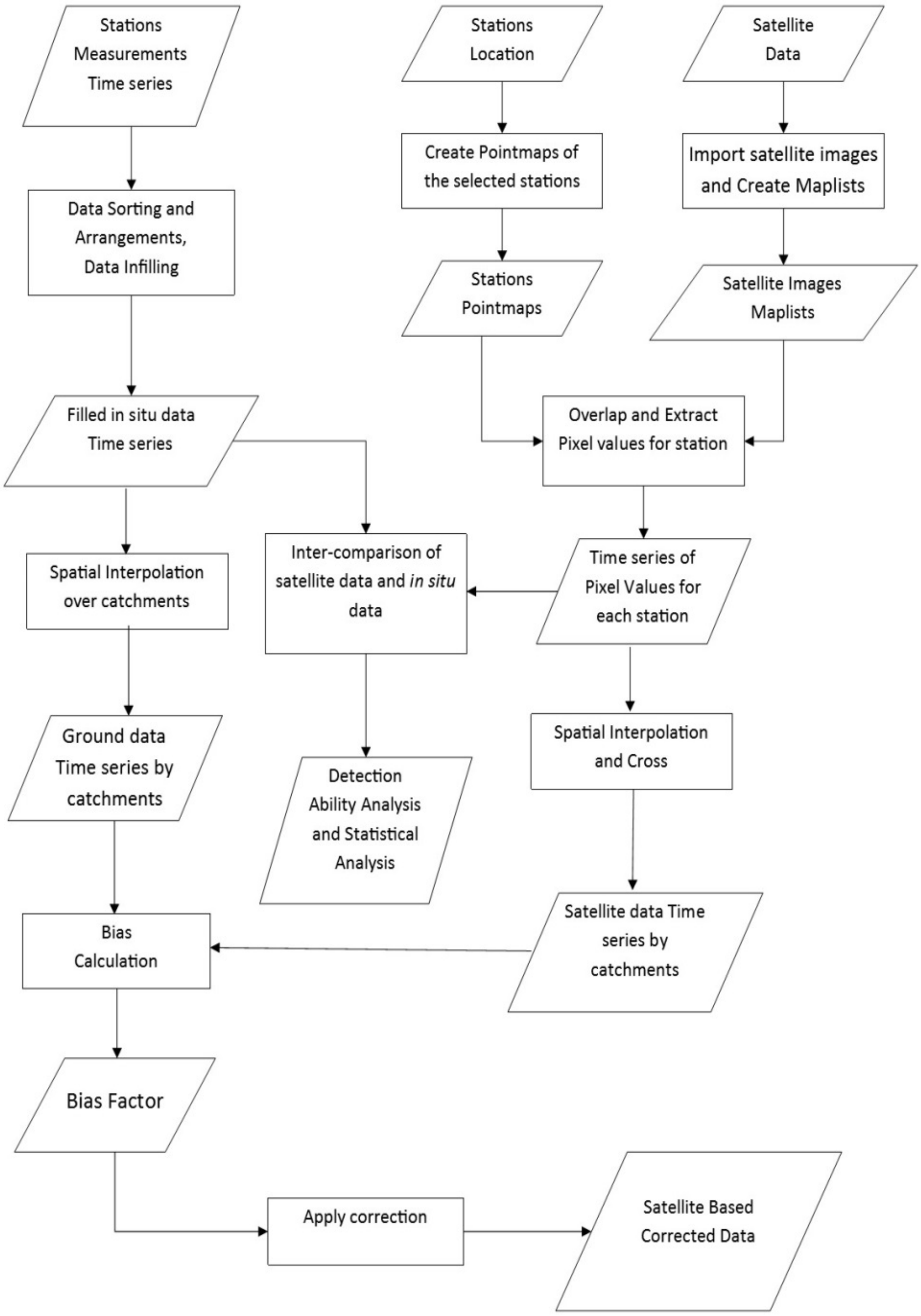

Figure 2: Flow chart for processing of satellite rainfall estimates in (Source: MSc study Sendama, 2015)

Table 1: Characteristics of some satellite rainfall products

Product	Geographic coverage	Period Coverage	Spatial resolution	Temporal resolution	Source
CMORPH 8km	Lat: 60°S - 60°N Lon: 180°W - 180°E	since 2002	0.07° (8km)	30min	ftp://ftp.cpc.ncep.noaa.gov/precip/CMORPH_V1.0/CRT/8km-30min
RFE 2.0	Lat: 40°S - 40°N Lon: 20°E - 55°E	since 2001	0.1°	24h	ftp://ftp.cpc.ncep.noaa.gov/fews/fewsdata/africa/rfe2/bin
TRMM 3B42 v7	Lat: 50°S - 50°N Lon: 180°W - 180°E	since 1998	0.25°	3h	http://disc2.nascom.nasa.gov/opendap/TRMM_L3/TRMM_3B42/

Satellite datasets from GEONETCast (text adapted from MSc study by Ataklti Tewelde, 2012)

The most relevant satellite datasets available through GEONETCast that are accessible in near real-time (e.g. 30' after observation or similar) are:

- MSG-MPE or Meteosat Second Generation Multi-sensor Precipitation Estimate (EUMETSAT)
- TAMSAT Rainfall (http://www.met.reading.ac.uk/~tamsat/data/)
- LandSAF MET or Meteosat Evapotranspiration estimate (produced by the LandSAF Facility) (http://landsaf.meteo.pt/)

MSG-MPE is a satellite precipitation estimate based on a blending technique or merging of microwave rainfall observation on-board the polar orbiting Defense Meteorological satellite program (DMSP) group of satellites and the geostationary observations of MSG (meteosat-9) and more precisely its thermal band at 10.8 µm, that monitors the top-of cloud temperatures and cold cloud duration. The MSG-MPE images are available in near real-time at a 15-minute resolution and for the entire MSG disk (window) at a 3-km spatial resolution. The combination of the relatively high spatial and temporal resolution makes the product is often preferred to other satellite rainfall products.

Images commonly are available in grib format and can be directly ingested by the ILWIS Open GEONETCast Toolbox. At ITC, the 15-minute images (96 scenes per day) are processed to daily sum-products (0015-2400) and made available to students and researchers via the itc-ftp-site in Ilwis format. This rolling archive contains the last 12 months of data, except the days when no 15 minutes data were distributed via EUMETSat, or a data transmission interruption occurred.

LandSAF - Meteosat evapotranspiration

LandSAF - Meteosat evapotranspiration (MET) and Daily Mean evapotranspiration (DMET) is an actual evapotranspiration estimate produced by the Land Surface Analysis (LSA-SAF). The MET products are available through the GEONETCast Digital Video Broadcast (DVB) data stream (30 minute intervals) or can be downloaded (DMET daily sum product) from the LandSAF website. Beside the 30-minute Evapotranspiration (ET) data available in near real time, the daily mean evapotranspiration (DMET) which is the actual daily evapotranspiration produced by the SAF for Land Surface Analysis (LSA-SAF) is freely available and can be processed using the Geonetcast-plug –in. Using the GlobCover land cover data (2009), the ETa for five different land cover classes could be evaluated for some sample areas with homogeneous land cover, as described in the GlobCover dataset legend. Land cover classes were extracted from Glob Cover 2009 dataset available at 300 m spatial resolution. The study area was masked and the actual evapotranspiration of different land cover classes were collected from MET LandSAF.

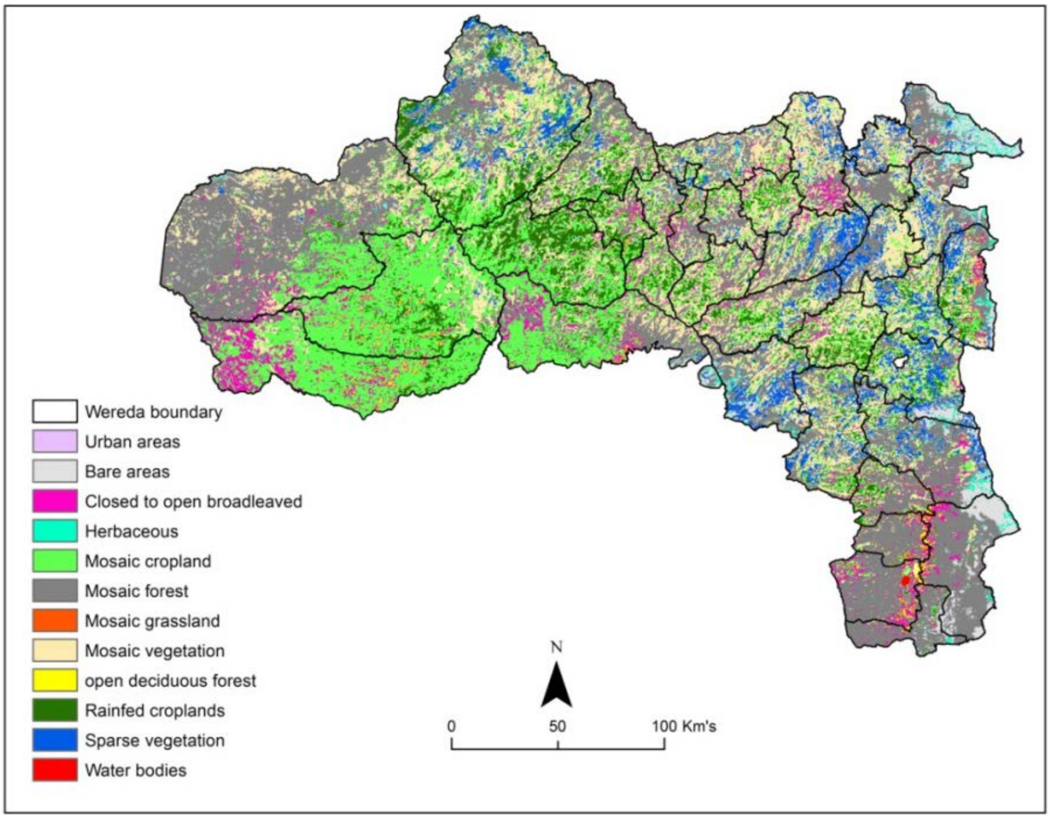

Fig: Tigray land cover classes map from GlobCover 2009 at 300 meter spatial resolution (Source: MSc study by Ataklti, 2012)

Table 2: Spatial and temporal resolution of the dataset used in (MSc study Ataklti, 2012)

Satellite Product	Resolution		Product	Resampled to		Data Type	Space Organisation / Satellite
	Space	Time		Space	Time		
MSG-MPE	3 km	15minute	Rainfall	10 km	10-day	Satellite	EUMETSAT
RFE2.0	~10 km	10-day	Rainfall	10 km	10-day	Gauge and satellite	NOAA
TAMSAT	~4km	10-day	Rainfall	10 km	10-day	Satellite	EUMETSAT
LSA-SAF	3 km	30 minute	DMET	3 km	Seasonal	Satellite	EUMETSAT
FEWS NET	~100 km	Daily	ETo	3 km	Seasonal	Satellite	NOAA
GlobCover	300 m	6 / year	Land cover	300 m	Seasonal	Satellite	ENVISAT
In-situ	Point	Daily	Meteorology	10 km	10- day	Gauge	Ground
Field data	point		soil moisture	point		Ground	Ground

Ataklti, T.Y. (2012). Assessing the potential of geonetcast earth observation and in situ data for drought early warning and monitoring in Tegray, Ethiopia. Enschede, University of Twente Faculty of Geo-Information and Earth Observation (ITC), 2012

Herman, A., Kumar, V. B., Arkin, P. A., & Kousky, J. V. (2010). Objectively determined 10-day African rainfall estimates created for famine early warning systems. Retrieved from http://www.tandfonline.com/doi/abs/10.1080/014311697217800#.VKp32CvF8m0

Huffman, G. J., Adler, R. F., Bolvin, D. T., & Nelkin, E. J. (2010). The TRMM Multi-Satellite Precipitation Analysis (TMPA), 3–22. doi:10.1007/978-90-481-2915-7

Joyce, R. J., Jonowiak, J. E., Arkin, P. A., & Xie, P. (2004). CMORPH : A Method that Produces Global Precipitation Estimates from Passive Microwave and Infrared Data at High Spatial and Temporal Resolution. doi:10.1175/1525-7541

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Thomas , H., Alessio, L., and Fausto, R. (2002). The Eumetsat Multi-Sensor Precipitaton Estimate(MPE) Retrieved 02/26, 2012. Retrieved from http://oiswww.eumetsat.int/~idds/html/doc/IPWG_2002_MPE.pdf